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Catch sustainability of the main fish species exploited by handline in locations with distinct management systems in Brazil

Jasna Maria Luna Marques [a,b,*], Caroline Vieira Feitosa [a]

[a] Institute of Marine Sciences - Labomar, Federal University of Ceará, Avenida da Abolição, 3207, 60165-081, Fortaleza, CE, Brazil
[b] Graduate Program in Tropical Marine Sciences, Federal University of Ceará, Brazil

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ABSTRACT

Ecological Risk Assessment for the Effects of Fishing (ERAEF) is an assignment process of magnitudes and probabilities to the damaging effects of fishing activities, and is used to identify and prioritize the risks of fishing to marine ecosystems. Productivity and susceptibility analysis (PSA), part of ERAEF, assumes that the susceptibility of a species to impact, and its productivity, determines the potential for recovery of the species if its population collapses. In this study, PSA of the species most caught by the handline fishery of the artisanal fleet from the state of Ceará, Northeast Brazil. Sampling was conducted by monitoring fishing landings from 2017 to 2019 at Mucuripe, Batoque marine protected area (MPA), and Prainha do Canto Verde MPA. The seven productivity attributes were maximum length (Lmax), von Bertalanffy growth coefficient (K), length at first maturity (L50), L50/Lmax, intrinsic growth rate (r), fecundity, and trophic level. The six susceptibility attributes were: availability (the geographic overlap of fishing activity according to species distribution), percentage of individuals caught larger than the L_{50}, management strategy, commercial category, frequency of occurrence, and abundance. The productivity values ranged from 1.24 to 2.88. The species *Scomberomorus cavalla* showed the lowest productivity, while *Holocentrus adscensionis* showed the highest productivity with a high r and K. Susceptibility values ranged from 1.18 to 2.27. The species *Lutjanus synagris* caught at Batoque MPA showed the highest susceptibility, which was a high commercial category score, frequency of occurrence, and abundance at this site. Vulnerability values ranged from 1.71 to 3.46. The species *S. cavalla*, *L. analis*, and *Ablennes hians* were the most vulnerable, ranked as high risk at all sites. *H. adscensionis* was the least vulnerable at all sites. The vulnerabilities were not statistically different across the sites, suggesting a lack of effective management measures in the MPA.

1. Introduction

Artisanal fisheries are characterized by small fishing vessels, using few resources, making short fishing trips, generally close to shore, and mainly focused on subsistence and local consumption (FAO, 2014). Brazilian law characterizes artisanal fishing as an activity carried out by professional fishers in an autonomous manner with their own gear, in small boats (with a gross tonnage smaller than 20) (Government of Brazil, 2020a). The Northeast region has the largest national annual fishing production with 186,012 t (in 2011), and of this, the state of Ceará contributed 21,788 t through artisanal fishing (MPA - Ministério da Pesca e Aquicultura, 2013). One of the techniques used by these fishers is the handline, a very common fishing gear in the state of Ceará, widely used across artisanal fishing communities, and is focused on one or more species that can be pelagic or demersal (Maia and Barreira, 2008; da Silva et al., 2007; Gadig et al., 2000). In this region, the catch is composed of a wide diversity of species with low specific abundance and at different depth ranges (Fonteles, 2011). However, the bycatch is not significant in this type of fishing, as what is not traded is used for subsistence consumption (Bevilacqua et al., 2019). Handline fishing uses a nylon line of varied size depending on the target, and one or more hooks on the extremities. The size of fishhooks influences the size of the prey caught, as smaller hooks catch smaller prey (Montealegre-Quijano et al., 2011).

Fishing directly impacts the ecosystem, which is also affected by other human activities (e.g. pollution, habitat modification); therefore, fishing must be managed to ensure a balanced ecosystem (Garcia et al., 2003). In recent decades, there has been a worldwide effort to move from single-species fisheries management to a more holistic approach (Vinther et al., 2004). Thus, important protocols have been developed (e.g., Ecosystem Based

* Correspondence to: Population Dynamics and Ecology of Marine Fish Laboratory (DIPEMAR), Institute of Marine Sciences (Labomar), Federal University of Ceará, Avenida da Abolição, 3207, 60165-081, Fortaleza, CE, Brazil.

E-mail address: jasnaluna@alu.ufc.br (J.M.L. Marques).

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Fisheries Management (EBFM) and Ecosystem Approach to Fisheries (EAF), which require going beyond the direct impacts of the species being targeted by fisheries. Thus, modifications to habitats and ecological communities must be understood and managed to improve the overall sustainability of the ecosystem (Hobday et al., 2011a). The fisheries management actions undertaken in Brazil are generally focused on a single species; therefore, in order to meet the EBFM mandate, methodologies such as the ecological risk assessment for the effects of fishing (ERAEF) are important to support the adaptive management of fisheries with limited data (Smith et al., 2007). ERAEF is used to identify and prioritize the potential risks of fishing in marine ecosystems (Hobday et al., 2011b). ERAEF has the advantage of being a simple methodology to apply, which can be used in data-poor fisheries (Dowling et al., 2015b; Honey et al., 2010), and is also used in reef ecosystem fisheries (Feitosa et al., 2008; Previero and Gasalla, 2020). It is mainly divided into three steps: the first is the Scale Intensity Consequence Analysis (SICA), primarily a qualitative step. This process involves analyzing the risk sources, potential impacts associated with each problem, and likelihood that a given level of consequence occurs. This combination produces an estimated level of comparative risk that can be used to help determine the level of response required for management (Fletcher, 2005). The second step is the Productivity and Susceptibility Analysis (PSA), a semiquantitative step that is based on the assumption that the risk to an ecological component will depend on two characteristics of the component units: (1) the extent of impact due to fishing activity, which is determined by the susceptibility of the species to fishing activities and (2) the recovery capacity, which determines the potential for the species to recover if its population collapses (Cotter and Lart, 2011). The third analysis uses the PSA results to propose appropriate management measures for the studied fisheries (Hobday et al., 2007). This methodology, like similar protocols, has already been used in other fisheries in Brazil with relevant results that can be considered in the formation of public policies (Feitosa et al., 2008; Previero and Gasalla, 2020; Lucena-Frédou et al., 2017).

Brazil has the National System of Conservation Units (SNUC), which includes federal, state, and municipal conservation areas with different goals according to their use. The Extractive Reserve, a type of marine protected area (MPA), is considered a sustainable use conservation area under SNUC, equivalent to IUCN VI (protected area with sustainable use of natural resources). These MPAs are used by traditional populations to protect their livelihoods and cultures (Government of Brazil, 2020b). These types of MPA are important tools for the conservation of marine biomes and fish stocks (Giraldi-Costa et al., 2020). The state of Ceará has two federal extractive reserves: Batoque (Government of Brazil, 2020c) and Prainha do Canto Verde (PCV) (Government of Brazil, 2020d), both of which are located in coastal and marine areas, and fishing is the main extractive activity. The Prainha do Canto Verde MPA is a marine area where fishing activity is regulated through fishery management agreements (ICMBIO - Instituto Chico Mendes de Conservação da Biodiversidade, 2012). It was established by a decree on June 5, 2009. Because it is a marine extractive reserve, the goals are focused on artisanal fishing activities practiced by the community members. The Batoque MPA was established by a decree on June 5, 2003. Despite being older, it does not have a management plan in place and also does not include the marine portion of the territory, which makes it difficult to achieve the objectives of the MPA. The goals of both the MPAs are to ensure sustainable use and conservation of renewable natural resources, and to protect the livelihoods and culture of the local extractive population.

Outside of the MPAs, there has been no regulation of fishing activity. Thus, it is necessary to conduct research to identify the ecological risks originating from artisanal fishing practiced in areas with some kind of protection, and in places located in large urban centers, as in the case of Mucuripe, which has the largest fishing fleet of Fortaleza, the capital of the state of Ceará (Menezes et al., 2019). Mucuripe has an important harbor for cargo and passenger transportation and intensive urban development. Unlike MPAs, Mucuripe is not inserted in any conservation area of SNUC. Marques et al. (2021), while analyzing the fishing data from the two MPAs mentioned above and Mucuripe, verified that Mucuripe employed the greatest fishing effort and caught the greatest number of species per boat among the three sites. During the compilation of manuscripts for the discussion of these study results, it was noted that Mucuripe, because it is located in the state capital and consequently has better access, in fact has a higher incidence of research than the other locations (Menezes et al., 2019; Santander-Neto and Faria, 2020; Lacerda et al., 2016). It is therefore important to carry out more extensive research that includes other fishing areas, such as the MPA analyzed in this study.

In this study, we aimed to analyze the productivity and susceptibility of the species most caught by the handline of the artisanal fleet fishery in the state of Ceará, northeastern Brazil. In addition, the results of the productivity and susceptibility analyses were compared between coastal and marine protected areas of sustainable use and other unprotected and unregulated areas in relation to the impact of fishing activity. This study applied a methodology from Australia and replicated it in this Brazilian case study to assess the ecosystem as a whole, moving away from single species management, which is still prevalent in Brazil and in many other countries globally.

2. Material and methods

2.1. Study area

Mucuripe beach is located at Mucuripe Cove in the city of Fortaleza, in the Brazilian state of Ceará (Fig. 1). Despite the environmental impacts of intense urban development (e.g., diffuse pollution sources, sewage, dredging, and landfill), fishers are still able to fish in this region and adjacent areas.

The Batoque MPA is a federal conservation area. It is located in the coastal region of the municipality of Aquiraz, in the Fortaleza Metropolitan Region, 51 km from the capital, and covers an area of approximately 601 ha (Fig. 1). There is still no management plan for the MPA.

The Prainha do Canto Verde MPA is also a federal conservation area. It is located in the municipality of Beberibe, State of Ceará, approximately 110 km from the capital, covering an area of approximately 29,794 ha (Fig. 1). There is a fisheries management agreement that regulates fishing activities in the area. In the fishing agreement it is established that only non-motorized boats are allowed in the area, as well as fishing gear and seasons that can be used (Feitosa et al., 2008)

2.2. Data collection

Because data were sampled in two federal conservation areas, this study needed authorization was required from the System for Authorization and Information in Biodiversity of the Chico Mendes Institute for Biodiversity Conservation (SISBIO-ICMBIO): licenses n° 61552-1 and n° 52552-2, as required by Brazilian legislation. The research ethics committee of the Federal University of Ceará approved the questionnaire submitted to local fishers (approval protocol no. 3.913.236).

Data were collected from May 2017 to April 2018 at Mucuripe beach, from July 2018 to June 2019 at Batoque MPA, and from

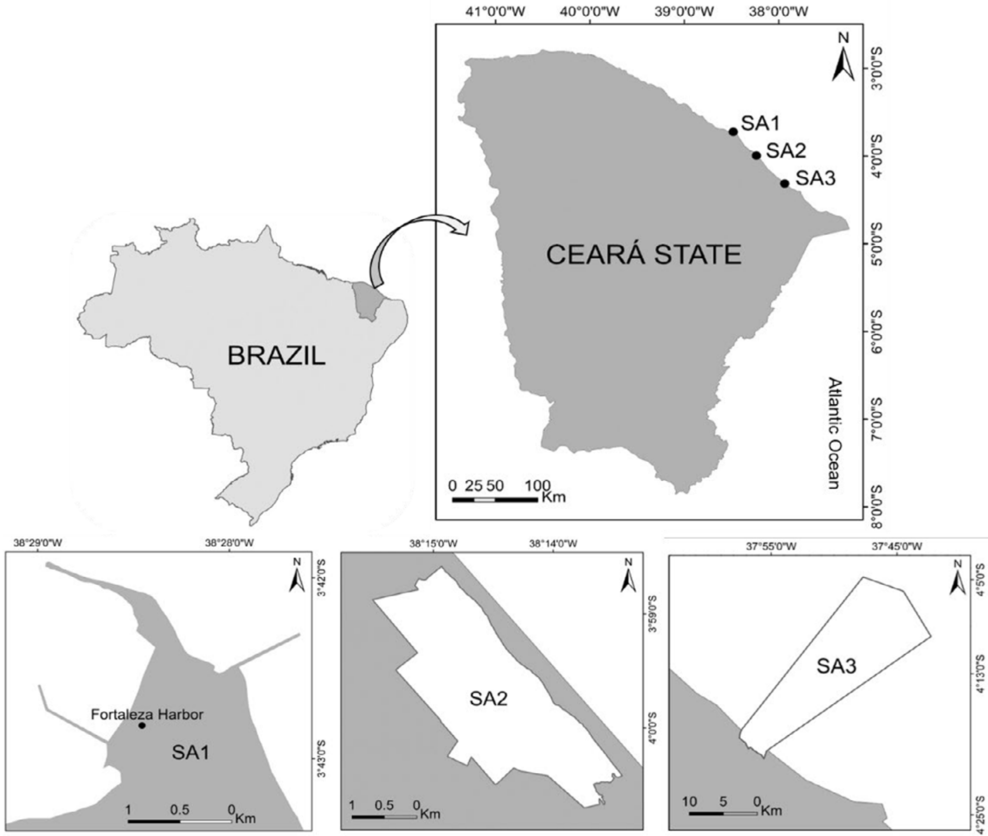

Fig. 1. Map of the study area showing Brazil, the state of Ceará and the three sites studied. Legend: SA1: Mucuripe beach, SA2: Batoque MPA, SA3: Prainha do Canto Verde MPA.
Source: Marques et al. (2021)

April 2017 to April 2018 at Prainha do Canto Verde MPA. The data were obtained through fishing landing monitoring, and the sampling frequency was twice a month. Ecological and biological data of the species that were published in scientific articles and/or available on the FISHBASE platform were obtained (Froese and Pauly, 2021). We also considered the threat categories in which the species are classified according to the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN), which categorizes the species into levels of risk of extinction: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD), to compare with the results of this research (IUCN, 2021). It is worth mentioning that none of the species considered in this study is in any category of threat, according to The Red Book of the Brazilian Fauna Threatened with Extinction (ICMBIO - Instituto Chico Mendes de Conservação da Biodiversidade, 2018).

The individuals sampled were identified at the species level by experienced researchers using identification keys (e.g. Haimovici et al., 2009; Last et al., 2016; Figueiredo and Menezes, 1980, 2000; Menezes and Figueiredo, 1978, 1980, 1985). The species chosen for analysis were divided into handline target species: lane snapper (*Lutjanus synagris*), mutton snapper (*Lutjanus analis*), dog snapper (*Lutjanus jocu*), yellowtail snapper (*Ocyurus chrysurus*), king mackerel (*Scomberomorus cavalla*), Serra Spanish mackerel (*Scomberomorus brasiliensis*), blue runner (*Caranx crysos*) and yellow jack (*Carangoides bartholomaei*), which are species with the greatest economic value; and handline non-target species: white grunt (*Haemulon plumierii*), squirrelfish (*Holocentrus adscensionis*), sheepshead porgy (*Calamus penna*), sand tilefish (*Malacanthus plumieri*), coney (*Cephalopholis fulva*), and flat needlefish (*Ablennes hians*), which are the species mainly used for subsistence. The eligibility criteria for these species were that the species most commonly caught by the handline fishery and those that occurred in the fisheries conducted at the three study sites.

2.3. Data analysis

In this research the first step of ERAEF, the SICA analysis, was not carried out formally. It was chosen discretionarily based on the reality of the landings, since the impacts of fishing on target and non-target species are well known in the literature. The absence of this step does not invalidate the ERAEF result (Hordyk and Carruthers, 2018). The second step (PSA) was performed. The seven productivity attributes were classified into ranges associated with three different levels of risk. If the productivity level associated with the attribute was high, its score was 1 (low risk); if it was medium, 2 (medium risk); and if it was low, 3 (high risk) (Hobday et al., 2011b).

In the case of susceptibility, the six attributes were also given scores of 1, 2or 3 depending on the possibility of the risk to exist. If the susceptibility level associated with an attribute was low, its score was 1 (low risk); if it was medium, 2 (medium risk); and if it was high, 3 (high risk) (Hobday et al., 2011b).

The attributes were chosen according to a previously established methodology (Hobday et al., 2011b) and widely applied in other fisheries (Cotter and Lart, 2011; Lucena-Frédou et al., 2017; Patrick et al., 2010). The attributes were chosen considering the characteristics of the fishery and site, in addition to data availability.

The risk limits for each attribute were selected using the quotient between the lowest and the highest values that is, the extremes found, divided by three. Thus, they were distributed into tertiles.

The seven productivity attributes (Table 1) were:

(1) Maximum length (Lmax, cm): the maximum total length of each species found in the literature. In this study, all species were within the limits reported by Froese and Pauly (2021). This parameter is considered a relative indicator of productive capacity (Patrick et al., 2010).

(2) von Bertalanffy growth coefficient (K, $cmyear^{-1}$): the growth rate or how fast the fish reaches its maximum length. The values are obtained from Froese and Pauly (2021). When this information was not available for a given species, the parameter was calculated according to the formula, $k = 2.15 \times L_{\infty}^{-0.46}$ (Le Quesne and Jennings, 2012).

(3) Length at first maturity (L50, cm): the length at which 50% of the individuals in a given population are capable of reproduction. The values were obtained from Froese and Pauly (2021). When this information was not available for a given species, the parameter was calculated according to the formula, $L_{mat} = 0.64 \times L_{\infty}^{0.95}$ (Le Quesne and Jennings, 2012).

(4) L50/Lmax: a ratio that describes the differences between somatic and reproductive investment per species. This quotient has a linear variance, being highly correlated, even in animals that change sex during their lifetime (Allsop and West, 2003).

(5) Intrinsic growth rate (r): a parameter that reflects population growth, and corresponds to the maximum growth rate of a population at its lowest possible stock. This is directly related to the productivity of the stock, and is a combination of other productivity attributes (Hordyk and Carruthers, 2018). The values of r were estimated using the formula, $r = 2F_{MSY}$. F_{MSY} is the maximum rate of fishing mortality (Zhou et al., 2018).

(6) Fecundity: the average number of oocytes produced by a female for a given time influenced by the length and age of the individual (Patrick et al., 2010). Fecundity is a parameter that is not available for several species, especially in data-poor stocks (Stobutzki et al., 2001). Fecundity values could not be obtained for some species, so these were categorized as high risk based on the precautionary principle (Hobday et al., 2011b). The fecundity of the other species was obtained from specialized literature (Sousa et al., 2017; Brule et al., 2018; Trejo-Martínez et al., 2011; Ivo, 1974; Lima et al., 2007; Santos, 2012; Oliveira et al., 2017; Shinozaki-Mendes et al., 2007, 2013; Garciov Filho and Simoni, 2019).

(7) Trophic level: The position of a species within the food web Lower trophic level stocks are generally more productive than higher ones (Patrick et al., 2010). Fishing has the ability to decrease the marine trophic index, suggesting that fish from the highest trophic levels are being removed from the ecosystem faster than they can recover, thus favoring species from lower trophic levels and deregulating the ecosystem (Pauly et al., 1998). Information on this parameter per species was obtained from Froese and Pauly (2021).

In total, 14 species and 7 productivity attributes were analyzed, totaling 98 parameters. However, for species *Ablennes hians*, *Calamus penna* and *Malacanthus plumieri* specific information about fecundity is not available, so the precautionary principle was used considering conservative values (Hobday et al., 2011b). This represented 3.06% of the total parameters used in the analysis.

The six susceptibility attributes (Table 2) were:

(1) Availability (horizontal overlap): a measure of the geographic overlap of fishing activity according to species distribution (MSC. Marine Stewardship Council, 2010). A qualitative analysis was performed based on the information available on the FISHBASE, IUCN websites, literature and in-house expertise (Froese and Pauly, 2021; IUCN, 2021; Carneiro et al., 2022). The greater the overlap of the fishery with the distribution of the species, the higher the level of risk because the fishery will affect a greater proportion of the stock (Patrick et al., 2010).

(2) Percentage of individuals caught larger than the L_{50} (%>L_{50}): the number of individuals captured of each species that had a total length equal to or greater than L50. Length frequency data at each studied site were used.

(3) Management strategy: The measurement of the scope of stocks exploited by management and governance measures. Species that do not have any type of regulation are considered to be at higher risk (Lucena-Frédou et al., 2017), since the management action is supposed to be efficient and consequently the risks on the species are mitigated. Management strategy data were collected from the literature and legislation.

(4) Commercial category: the measure of market desirability or commercial value of the species (in dollars). The higher the sales price of a species, the higher the risk of overfishing (Patrick et al., 2010) because of the high prices, fishers will probably try to catch the most valuable species (Macusi et al., 2017). The sales prices of the fish were collected at the fishing landings.

(5) Frequency of occurrence (FO, %): The frequency of occurrence was obtained as the ratio of the total number of occurrences of a species by the number of samples performed. A high frequency of occurrence suggests high susceptibility to capture. The more often a species is fished, the greater is the risk of overfishing.

(6) Abundance (%): a measure of the number of individuals of a species caught in relation to the total sample. High abundance suggests high susceptibility to the fishing gear. The higher the abundance of a species caught, the more susceptible it is it would be to overfishing. Information regarding frequency of occurrence and abundance was obtained from the data collected at the time of landing at the three sampling sites.

According to Lucena-Frédou et al. (2017), each productivity and susceptibility attribute received a score according to its degree of importance, considering the ecological and biological criteria that are more or less relevant. For the productivity attributes, Lmax, k, and r received a score of 3, and the others received a score of 2. The susceptibility attributes received a score of 2, except for the management strategy that received a score of 1. A pondered average of the attributes was then performed to calculate the vulnerability of each species by site.

The vulnerability of each species is given by:

$$V = \sqrt{[(P - X_0)^2 + (S - Y_0)^2]} \quad (1)$$

This risk can be graphically represented on a Cartesian plane, where productivity is on the abscissa axis and susceptibility on the ordinate axis. The graph can be divided into "risk areas" which are the three zones that correspond to low, medium or high-risk levels (Cotter and Lart, 2011).

To determine significant differences between the data from the sampled sites, tests for normality of the data and homoscedasticity of variances were performed using the Shapiro–Wilk and Levene tests, respectively (Shapiro and Wilk, 1965). As the prerequisites were met, an analysis of variance (ANOVA), followed by a post hoc pairwise comparison using the Tukey HSD test, was performed. Statistical analyses were performed using PAST® software (Hammer et al., 2001). All analyses were performed at a significance level of 5%.

3. Results

A total of 43 landings at Mucuripe, 69 at Batoque, and 142 at Prainha do Canto Verde were sampled and distributed among 254 vessels fishing with handline gear. The 14 species surveyed belonged to nine families and 11 genera (Table 3).

Productivity values ranged from 1.24 to 2.88 (Table 8). Species productivity values were equal across the sites as they are common values for each species (Table 4). *Scomberomorus cavalla*

Table 1
Attributes and productivity scores of species sampled between 2017 and 2019 in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil. High productivity: score 1; medium productivity: score 2; low productivity: score 3.

Productivity attributes	High productivity, Low risk (score = 1)	Medium productivity, Medium risk (score = 2)	Low productivity, High risk (score = 3)
Lmax (cm)	<90.67	90.67–137.33	>137.33
K (cm, year-1)	>0.24	0.15–0.24	<0.15
L50 (cm)	<33.06	33.06–51.52	>51.52
L50/Lmax	<0.34	0.34–0.45	>0.45
r	>0.88	0.55–0.88	<0.55
Fec (millions of oocytes)	>5.64	2.82–5.64	<2.82
Trophic level	<3.57	3.57–4.03	>4.03

Table 2
Attributes and susceptibility scores of species sampled between 2017 and 2019 in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil. Low susceptibility: score 1; medium susceptibility: score 2; high susceptibility: score 3. Legend: 1 USD = 5.31 BRL.

Susceptibility attributes	Low susceptibility, Low risk, (score = 1)	Medium susceptibility, Medium risk, (score = 2)	High susceptibility, High risk, (score = 3)
Availability	Global distribution	Widely distributed beyond the fishing zone	Distribution mainly restricted to fishing area
%> L50	>72.47	52.94–72.47	<52.94
Management strategy	Currently subject to a several conservation and management measures	No specific regulation is in effect, but some indirect measures are in course	No regulation is in effect
Commercial category	<1.88	1.88–2.82	>2.82
Frequency of occurrence	Infrequent	Moderate frequency	Very frequent
Abundance	Not abundant	Moderate abundance	Very abundant

Table 3
List of species sampled in order of evolution according to Nelson et al. (2016), local names, English common names and species code of the species surveyed in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil.

Family	Species	Local name	English common name	Species code
Holocentridae	*Holocentrus adscensionis* (Osbeck, 1765).	Mariquita	Squirrelfish	HAD
Belonidae	*Ablennes hians* (Valenciennes, 1846)	Zambaia	Flat needlefish	AHI
Carangidae	*Carangoides bartholomaei* (Cuvier, 1833)	Guarajuba amarela	Yellow jack	CBA
	Caranx crysos (Mitchill, 1815)	Guarajuba branca	Blue runner	CCR
Scombridae	*Scomberomorus brasiliensis* Collette, Russo & Zavala-Camin, 1978	Serra	Serra Spanish mackerel	SBR
	Scomberomorus cavalla (Cuvier, 1829)	Cavala	King mackerel	SCA
Serranidae	*Cephalopholis fulva* (Linnaeus, 1758).	Piraúna	Coney	CFU
Malacanthidae	*Malacanthus plumieri* (Bloch, 1786)	Pirá	Sand tilefish	MPL
Haemulidae	*Haemulon plumierii* (Lacepède, 1801)	Biquara	White grunt	HPL
Lutjanidae	*Lutjanus analis* (Cuvier, 1828)	Cioba	Mutton snapper	LAN
	Lutjanus jocu (Bloch & Schneider, 1801).	Dentão	Dog snapper	LJO
	Lutjanus synagris (Linnaeus, 1758)	Ariacó	Lane snapper	LSY
	Ocyurus chrysurus (Bloch, 1791)	Guaiuba	Yellowtail snapper	OCH
Sparidae	*Calamus penna* (Valenciennes, 1830)	Pena	Sheepshead porgy	CPE

Table 4
Productivity analysis of species sampled between 2017 and 2019 in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil.

Productivity attributes	Risk value													
	HAD	AHI	CBA	CCR	SBR	SCA	CFU	MPL	HPL	LAN	LJO	LSY	OCH	CPE
Lmax (cm)	1	3	2	1	2	3	1	1	1	2	2	1	1	1
K (cm, year-1)	1	2	2	1	3	3	3	1	2	3	3	2	3	1
L50 (cm)	1	3	2	1	2	3	1	2	1	3	1	1	1	1
L50/Lmax	1	3	2	2	1	2	1	3	2	3	1	2	1	3
r	1	2	3	2	3	3	3	2	2	3	3	2	3	1
Fec (millions of oocytes)	3	3	3	3	1	3	3	3	3	2	1	2	3	3
Trophic level	1	3	3	3	1	3	3	2	2	2	3	2	2	3

obtained the highest risk scores, scoring almost all attributes with maximum risk (Table 4). On the other hand, *Holocentrus adscensionis* obtained the lowest risk scores for productivity, showing a high intrinsic growth rate (r) and a high von Bertalanffy growth coefficient (k). It is important to note that risk scores are inversely proportional to productivity.

Susceptibility values ranged from 1.18 to 2.27 (Table 8). Susceptibility scores by species at each site can be seen in (Table 5, Table 6 and Table 7). The species *Lutjanus synagris* at Batoque beach had the highest susceptibility score, justified by the high score for commercial category, frequency of occurrence, and abundance of this species at this site (Table 6).

Vulnerability values ranged from 1.71 to 3.46, with species falling in all risk categories, with the medium risk category being the most abundant. The species *S. cavalla*, *L. analis*, and *Ablennes hians* were the most vulnerable, ranking as high risk at all sites. *H. adscensionis* was the least vulnerable, being the only species ranked as low risk at all sites (Table 8).

Fig. 2 shows the graph of the PSA of the species in the three sites divided by risk zones. The increase in risk occurs as one moves towards the upper right corner of the graph, while the opposite occurs as one moves towards the opposite region. While considering the calculated vulnerabilities for the species by site,

Table 5
Susceptibility analysis of the species sampled in Mucuripe, CE, Brazil.

Susceptibility attributes	Risk value													
	HAD	AHI	CBA	CCR	SBR	SCA	CFU	MPL	HPL	LAN	LJO	LSY	OCH	CPE
Availability	1	1	1	1	1	1	1	1	1	1	1	1	1	1
%> L50	1	1	1	1	1	1	1	1	1	2	1	1	1	1
Management strategy	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Commercial category	1	1	2	2	3	3	1	1	2	3	2	2	2	1
Frequency of occurrence	2	1	1	1	2	3	2	2	3	3	3	3	3	1
Abundance	2	1	1	1	1	1	2	1	2	1	1	1	2	1

Table 6
Susceptibility analysis of species sampled in the Batoque MPA, CE, Brazil.

Susceptibility attributes	Risk value													
	HAD	AHI	CBA	CCR	SBR	SCA	CFU	MPL	HPL	LAN	LJO	LSY	OCH	CPE
Availability	1	1	1	1	1	1	1	1	1	1	1	1	1	1
%> L50	1	2	1	1	1	1	1	2	1	2	1	1	2	1
Management strategy	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Commercial category	1	2	2	2	3	3	1	2	2	3	3	3	2	2
Frequency of occurrence	1	2	1	2	2	2	1	1	1	2	1	3	1	2
Abundance	1	1	1	1	1	1	1	1	1	1	1	3	1	1

Table 7
Susceptibility analysis of species sampled in the PCV MPA, CE, Brazil.

Susceptibility attributes	Risk value													
	HAD	AHI	CBA	CCR	SBR	SCA	CFU	MPL	HPL	LAN	LJO	LSY	OCH	CPE
Availability	1	1	1	1	1	1	1	1	1	1	1	1	1	1
%> L50	1	2	1	1	1	1	1	3	1	2	1	2	1	3
Management strategy	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Commercial category	1	1	1	1	2	3	1	1	1	2	3	2	1	1
Frequency of occurrence	1	1	1	1	2	2	1	1	1	2	1	1	2	1
Abundance	1	1	1	1	1	1	1	1	3	1	1	1	2	1

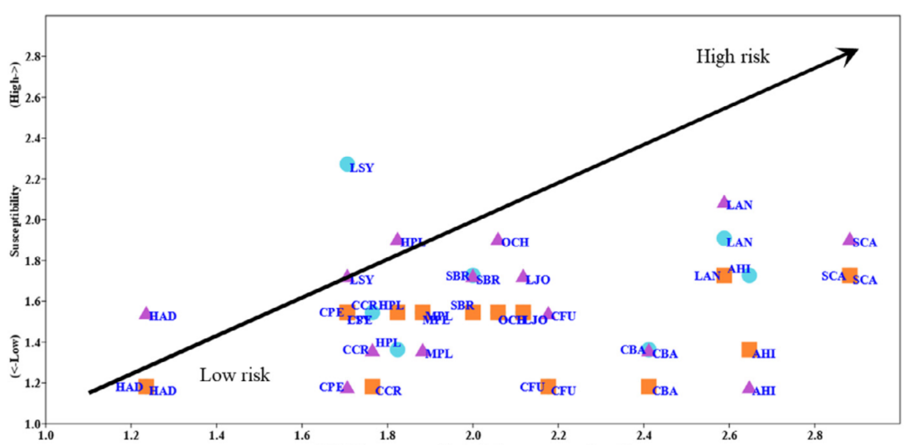

Fig. 2. Distribution of productivity and susceptibility of species caught in the handline fishery and sampled between 2017 and 2019 in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil. Legend: blue circle: Batoque MPA; purple triangle: Mucuripe; orange square: PCV MPA. Species codes are in Table 3. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

it was observed that the vulnerabilities did not differ statistically between the sampled areas. (One-way ANOVA, p .8154.)

4. Discussion

The PSA carried out in this research is a helpful technique, because it is a comprehensive methodology that can be adapted to different types of fisheries, enabling localities that are poor in data and lack official statistics to provide with information that can help them formulate management strategies (Dowling et al., 2015a; Honey et al., 2010). This is possible because this technique relies on available ecological and biological data of fish species to estimate their productivity and susceptibility. However, it is important to note that this methodology focuses only on the impacts of fishing on the species. Therefore, anthropogenic and environmental impacts were not assessed in this study. The species most commonly caught by the fishery at the three sites were evaluated, and it was observed that none of these species has a specific management tool for it (e.g., closed season, minimum catch size, among others). Perhaps it is because none of them fit any threat criteria on a national and international basis (IUCN, 2021; ICMBIO - Instituto Chico Mendes de Conservação da Biodiversidade, 2018). The species *H. adscensionis* was the least vulnerable in this study, and this value was influenced by the high productivity of the species, e.g., high intrinsic growth rate (r), high von Bertalanffy growth coefficient (k), and low length at first maturity (L50).

Table 8
Risk category in decreasing order of vulnerability of species caught in the handline fishery in Mucuripe, Batoque MPA and PCV MPA, CE, Brazil. In red are species considered high risk, in yellow, medium risk, and in green, low risk. The species risk categories according to IUCN are Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD). Species codes are in Table 3.

Species	Study site	P	S	V	Rank	Risk category	IUCN
SCA	Mucuripe	2.88	1.91	3.46	1	High	LC
SCA	Batoque	2.88	1.73	3.36	2	High	LC
SCA	PCV	2.88	1.73	3.36	3	High	LC
LAN	Mucuripe	2.59	2.09	3.33	4	High	NT
LAN	Batoque	2.59	1.91	3.22	5	High	NT
AHI	Batoque	2.65	1.73	3.16	6	High	LC
LAN	PCV	2.59	1.73	3.11	7	High	NT
AHI	PCV	2.65	1.36	2.98	8	High	LC
AHI	Mucuripe	2.65	1.18	2.90	9	High	LC
LSY	Batoque	1.71	2.27	2.84	10	Medium	NT
OCH	Mucuripe	2.06	1.91	2.81	11	Medium	DD
CBA	Batoque	2.41	1.36	2.77	12	Medium	LC
CBA	Mucuripe	2.41	1.36	2.77	13	Medium	LC
LJO	Mucuripe	2.12	1.73	2.73	14	Medium	DD
CBA	PCV	2.41	1.18	2.69	15	Medium	LC
CFU	Mucuripe	2.18	1.55	2.67	16	Medium	LC
SBR	Batoque	2.00	1.73	2.64	17	Medium	LC
SBR	Mucuripe	2.00	1.73	2.64	18	Medium	LC
HPL	Mucuripe	1.82	1.91	2.64	19	Medium	LC
LJO	Batoque	2.12	1.55	2.62	20	Medium	DD
LJO	PCV	2.12	1.55	2.62	21	Medium	DD
OCH	Batoque	2.06	1.55	2.57	22	Medium	DD
OCH	PCV	2.06	1.55	2.57	23	Medium	DD
SBR	PCV	2.00	1.55	2.53	24	Medium	LC
CFU	Batoque	2.18	1.18	2.48	25	Medium	LC
CFU	PCV	2.18	1.18	2.48	26	Medium	LC
MPL	Batoque	1.88	1.55	2.44	27	Medium	LC
MPL	PCV	1.88	1.55	2.44	28	Medium	LC
LSY	Mucuripe	1.71	1.73	2.43	29	Medium	NT
HPL	PCV	1.82	1.55	2.39	30	Medium	LC
CCR	Batoque	1.76	1.55	2.35	31	Medium	LC
MPL	Mucuripe	1.88	1.36	2.32	32	Medium	LC
CPE	Batoque	1.71	1.55	2.30	33	Medium	LC
LSY	PCV	1.71	1.55	2.30	34	Medium	NT
CPE	PCV	1.71	1.55	2.30	35	Medium	LC
HPL	Batoque	1.82	1.36	2.28	36	Low	LC
CCR	Mucuripe	1.76	1.36	2.23	37	Low	LC
CCR	PCV	1.76	1.18	2.12	38	Low	LC
CPE	Mucuripe	1.71	1.18	2.08	39	Low	LC
HAD	Mucuripe	1.24	1.55	1.98	40	Low	LC
HAD	Batoque	1.24	1.18	1.71	41	Low	LC
HAD	PCV	1.24	1.18	1.71	42	Low	LC

(continued on next page)

Table 8 (continued).

In the northeast of Brazil, Previero and Gasalla (Previero and Gasalla, 2020) conducted a productivity and susceptibility analysis for some of the species evaluated in this study. In that study, the species *L. synagris*, *Ocyurus chrysurus*, and *Cephalopholis fulva* received a low vulnerability risk score for overfishing, and the species *L. jocu* and *Haemulon plumierii* were at medium risk. In this study, the five species mentioned it had a medium level of vulnerability. The past official statistics for the northeastern region of Brazil had shown that lutjanids were a highly captured and slow-growing species and are therefore highly vulnerable to overfishing (Resende et al., 2003). In this study, all lutjanids and *H. plumierii* had $k < 0.16$, indicating a slow growth rate. The results of this study were more conservative than those of Previero and Gasalla (2020), ranking most species at moderate risk. It is also important to point out that the attributes were adapted to the characteristics of the fisheries practiced in the region and were dependent on the data obtained.

Lucena-Frédou et al. (2017) conducted a PSA for the scombrid fishery in the Atlantic and Indian Ocean, including the species *S. cavalla* and *S. brasiliensis*, which were considered as a bycatch, and found a moderate risk level for the former and a high risk level for the latter. But, in this study, the former had a high risk, and the latter had a moderate risk. The species *S. cavalla* is classified as Least Concern by the IUCN (IUCN, 2021); however, it received a high risk in this research. It is important to note that this species is widely distributed from the western Atlantic to the eastern Atlantic, exhibiting little concern on a global scale (IUCN, 2021). However, taking into consideration the high commercial value and high frequency of occurrence in the landings, which ranked the species as high risk, it is recommended that more information on the status of the species is needed for a risk reduction strategy on a regional scale.

The lack of local data on this species is a matter of concern. Most commercially exploited marine fishes in Brazil suffer from a lack of data and monitoring of their status (OCEANA, 2020). Many species lack the basic data on their population parameters. These species are the least commercially valuable ones, being valued at less than US$1.88. An example of this is the species *A. hians*, which is sold for just US$0.94 per kilogram but classified with a high level of vulnerability, being influenced by the high L50 and low fecundity of the species. All highly caught species are at risk of being overfished one day, regardless of whether they are commercially valuable. Following a precautionary approach, the lack of data on non-target species in the literature by itself takes them to a high alert level (Johannes, 1998). This is not a problem in Brazil alone; even in developed countries such as Norway, it has been found necessary to increase efforts and adopt tools to assess their economically less important stocks (Gullestad et al., 2017).

The lack of statistical data on fishing in Brazil is another cause of concern. FAO (FAO, 2020) in its report "The state of fisheries and aquaculture in the world'' highlighted Brazil in a negative way for not having provided statistical data to the institution since 2014. Without statistics and effective legislations, there is no way to efficiently manage fishery resources, and this permeates all levels of the fishing organizations in the country (Resende et al., 2003). The lack of long-term commitment, investment, and financial resources makes the sustainable development of small-scale fisheries in Brazil unfeasible in the current scenario (Araujo et al., 2017; Previero and Gasalla, 2020).

The creation of marine protected areas has been a widely used strategy to preserve the continuity of species and the livelihoods of traditional populations, such as those benefiting from the marine protected area system (Gerhardinger et al., 2009). These areas should be periodically monitored and have well-defined rules incorporated in their management plans to ensure that the objectives of these areas are met. In both MPAs studied, the majority of the community is in favor of the rules, but there is no data to quantify these values. Without management plans, as observed in most marine protected areas in Brazil, management objectives are not achieved (ICMBIO - Instituto Chico Mendes de Conservação da Biodiversidade, 2021). It is important to reinforce the acceptance of the MPA by the community for its effectiveness (Cicin-Sain and Knecht, 1998). There is a need for broad stakeholder participation and buy-in added to adequate enforcement and monitoring for success in reaching the goal of combating overfishing in the area. Marques et al. (2021) performed a complete characterization of the fisheries in these three locations and observed that fishing effort was significantly lower in areas under some type of fisheries management than in an area outside of them. This may be an indication that both MPAs have some effectiveness, in terms of governance. However, in this study, no differences in species vulnerability were observed between the MPA and the external fishing area (unprotected area), indicating that even after more than ten years of creation of the protected areas, they were not effective in significantly protecting their resources.

Artisanal fishing activity is of great social importance, and it is extremely necessary that the status of the affected populations is known for its execution to be well ordered (Cardinale et al., 2014). It is important to work together with fishers and local communities. The ERAEF is convenient because it can address the main concerns of the stakeholders. Thus, stakeholders are more capable of engaging in management (Honey et al., 2010; Hornborg et al., 2018). Local fishers are the main beneficiaries of a well-designed fishery resource management policy, as they are directly impacted when fishing becomes unviable. In a study conducted in Prainha do Canto Verde, Carvalho et al. (Carvalho et al., 2010) pointed out that fishing in many cases did not supply for the fishermen and their families' basic needs, and the fish product was used only for their own consumption. It is necessary to value the work of these professionals, and in this sense, scientific research comes with the intention of giving alternatives so that the population can live with dignity. One cannot forget that sustainable development is built on three pillars, one of which is the social one (UN - United Nations, 1987).

It is important to emphasize that although this study dealt with species widely caught in the fisheries of the northeastern region, none of these are listed in Ordinance No. 445 of 2014 of the Ministry of Environment (MMA), the most recent list of threatened species published in the country (MMA - Ministério do Meio Ambiente, 2021); and none of these species are classified as vulnerable by the Red Book of the Brazilian Fauna threatened with extinction (ICMBIO - Instituto Chico Mendes de Conservação da Biodiversidade, 2018). Moreover, the IUCN listed most of the species in this study as least concern. This shows that although many species studied were left with medium and high vulnerabilities, these fisheries require more efficient management to ensure that they can continue to be practiced. As stated by Preikshot and Pauly (2005), the coexistence between conservation and fisheries is completely possible and necessary. In terms of conservation, if it is looked at from a functionalist point of view, humans are also part of nature that needs to be protected (Callicott et al., 1999).

5. Conclusions

The productivity and susceptibility analysis used in this study proved to be an efficient methodology for the preliminary assessment of data-poor fisheries that can be used as a framework for management measures. This research also serves as a basis for listing some species that should be prioritized in the management strategies for the region's fisheries resources. Further evaluation of the species *Ablennes hians, Carangoides bartholomaei, Lutjanus analis, Lutjanus jocu, Lutjanus synagris, Ocyurus chrysurus, Scomberomorus brasiliensis, and S. cavalla.*

Although the management intensities differed between the sites studied, there were no differences in species vulnerability between them. This suggests a weak differentiation in fishing methodologies (e.g., same fishing gear, same type of vessel) between the study sites and, consequently, in the impact caused by the fishery. However, it is important to emphasize that handline fishery is one of the selective forms of fishery and that all the species caught in the sites studied are used for both local commerce and subsistence, with no discarding individuals.

Some recommendations that would contribute to the management and protection measures for artisanal fisheries stocks are proposed here.

- Create incentives and make investments in scientific studies to determine the population parameters of all the component species, which are widely captured in artisanal fisheries.

- Develop management plans for the conservation areas that have not yet been developed, with emphasis on conservation and the continuous evaluation and management of fish stocks.

- Strengthen governmental integration with the productive chain of fish and all social actors involved.

- Implement strategic management based on studies and constant and long-term monitoring of fishery and commercial stocks, generating a statistical database of these fisheries.

CRediT authorship contribution statement

Jasna Maria Luna Marques: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Caroline Vieira Feitosa:** Conceptualization, Validation, Formal analysis, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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